EFFECTIVE DETECTION AND ELIMINATION OF IMPULSE NOISE FOR RELIABLE 4:2:0 YCBCR SIGNALS PRIOR TO COMPRESSION ENCODING

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ABSTRACT

This paper presents an efficient two-stage filtering method that provides highly reliable 4:2:0 YCbCr signals, which are widely used in the image- and video-processing community. In the first phase, we use an index mapping, center-weighted median filter (IMCWMF) to detect and remove noise from luminance (Y) components while inheriting the chrominance components (Cb and Cr) for the selected median luminance. In the second phase, we use a downsampling sigma filter (DSF) to detect and remove noise from the chrominance components while performing the downsampling process. Simulation results indicate that the proposed method outperforms other nonlinear filters in terms of both noise attenuation and signal-detail preservation while providing accurate color channel information for the JPEG compression process and overall image quality.

1. INTRODUCTION

Impulse noise can corrupt color images due to faulty sensors or channel transmission errors. Noise reduction is an important step in color image-processing applications. The most common way to filter out noise from color images is nonlinear median processing. Examples include the vector median filter (VMF) [1], the basic vector directional filter (BVDF) [2], and the general vector directional filter (GVDF) [2]. These nonlinear filters, based on the ordering of vectors in a predefined sliding window, are particularly effective at suppressing impulse noise in color images. However, when they are applied to an image uniformly, undesired processing of noise-free samples results in edge and texture blurring. To achieve an optimal balance between signal-detail preservation and noise attenuation, several researchers have investigated impulse detector algorithms prior to filtering [3][4][5]. These impulse detector schemes address the problem of blurring noise-free samples by selectively applying the median filter only to regions where there is impulse noise.

However, these nonlinear filters, including impulse detector prefilters, are performed on the RGB channels, which do not correspond to the perceptual attributes of human vision. Because of this, they blur fine details and edges in the YCbCr channels during RGB to YCbCr color conversion [6]. Thus, these filters fail to provide accurate YCbCr signals for further color image- and video-processing applications. In particular, MPEG and JPEG algorithms that employ well-known 4:2:0 (chroma downsampling) YCbCr formats [6][7] require an accurate input luminance channel prior to encoding because the human eye is more sensitive to luminance than chrominance components. Therefore, an efficient prefiltering scheme based on the YCbCr color space is necessary to provide reliable 4:2:0 YCbCr channels for color image- and video-processing applications.

In this paper, we present an efficient two-stage filtering scheme, called the hybrid index mapping, downsampling filter (HIMDF), which identifies and removes impulse noise to provide reliable 4:2:0 YCbCr channels. The HIMDF, based on the adaptive center-weighted median filter (ACWMF) [4] and the sigma filter (SF) [5] to focus the filter only on noisy samples, is applied to the human perceptual color space (e.g., YCbCr) to achieve optimal filtering properties over color channels. This approach provides accurate 4:2:0 YCbCr channels prior to the compression process and overall image quality.

2. REVIEW OF IMPULSE DETECTOR FILTERS

2.1. The adaptive center-weighted median filter

The ACWMF is an efficient filtering scheme that preserves desired signal features while efficiently removing noise elements by making adaptive tradeoffs between the identity filter and the median filter [4]. Let the window size be $(2h+1)^2$ and $L=2h(h+1)$. The functionality of the ACWMF is defined as

$$y_{ij}^{2k} = \text{median}\{x_{i-s,j-t}, (2k)\Diamond x_{ij} \mid -h \le s,t \le h\} \quad (1)$$

where $2k$ is the weight given to the center pixel (i,j), and $\Diamond$ represents the repetition operation. Clearly, y_{ij}^{0} (i.e., k=0) is the output of the standard median filter, whereas y_{ij}^{2k} is the output of the identity filter when $k \geq L$. For the current pixel x_{ij} under consideration, the differences are defined as

$$d_k = | y_{ij}^{2k} - x_{ij} | \qquad (2)$$

where k = 0, 1, …, L-1. For $k \geq 1$, the condition $d_k \leq d_{k-1}$ is satisfied, see [8].

To evaluate whether the current pixel is corrupted, the ACWMF employs a set of thresholds T_k, where $T_{k-1} > T_k$ for k = 1, 2, …, L-1. The ACWMF then filters only on the corrupted pixels while performing the identity operation (no filtering) for noise-free samples. The output of the ACWMF is defined as

$$y_{ACWMF} = \begin{cases} y_{ij}^{0}, & \text{if } \exists k,\ d_k > T_k \\ x_{ij}, & \text{otherwise} \end{cases} \qquad (3)$$

where y_{ACWMF} denotes the final estimate of the current pixel x_{ij}. Consider an example of a 3×3 window (i.e., h = 1 and L = 4), in which four thresholds T_k, k = 0, 1, …, 3, are needed. The median of the absolute deviations from the median (MAD), which is defined as

$$MAD = \text{median}\{| x_{i-s,j-t} - y_{ij}^{0} | : -h \leq s,t \leq h\} \qquad (4)$$

is a robust estimate of dispersion [9], and its scaled forms are used as the thresholds. The thresholds are defined as

$$T_k = s \cdot MAD + \delta_k,\ 0 \leq k \leq 3, \qquad (5)$$

with $[\delta_0, \delta_1, \delta_2, \delta_3] = [40, 25, 10, 5]$, and $0 \leq s \leq 0.6$ in suppressing random-valued impulse noise for various images, see [4]. We use this choice of parameters (with s=0.3) to identify and remove random-valued impulse noise from the luminance components in the YCbCr color space. Note that fixed-valued impulse noise corresponding to 0 or 255 in the RGB signals is represented by random-valued noise within the dynamic range of [16, 235] for luminance and [16, 240] for chrominance components through the shifting and scaling processes of the color conversion [6].

2.2. The standard sigma filter

The sigma filter, proposed by Lee [5], identifies impulse noise for noisy gray-scale images by utilizing the standard deviation measure, given by

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \qquad (6)$$

where μ is the mean of N input data $x_1, x_2, \ldots, x_N$, within a window of size N. The output y of the sigma filter is defined as

$$y_{SF} = \begin{cases} f(x_1, x_2, \ldots, x_N), & \text{if } |x_{(N+1)/2} - \mu| > k\sigma \\ x_{(N+1)/2}, & \text{otherwise} \end{cases} \qquad (7)$$

where $x_{(N+1)/2}$ is the central sample, k is the smoothing parameter, and the smoothing function $f(\cdot)$ is defined as the median of the input set. If the condition $d_k = | x_{(N+1)/2} - \mu | > k\sigma$ is satisfied, the central sample is detected as a likely noisy sample, and the smoothing function $f(\cdot)$ is performed on the input set. Otherwise, the central sample is considered noise-free, and no filtering operation is performed. The smoothing parameter k determines the filtering operation of the filter, varying from the uniformly smoothing filter operation (k=0) to the identity operation ($k \to \infty$). In the rest of paper, we use the standard choice of k=1 to identify and remove noise from chrominance components in the YCbCr color space.

3. OUR METHOD: HIMDF

The goal of our prefiltering method is to provide reliable 4:2:0 YCbCr channels not reachable by other nonlinear filters. Other nonlinear filters provide robust estimation in color images corrupted by bit errors and impulse noise. However, they introduce the undesired effect of blurring some edges and signal details in the YCbCr channels when RGB to YCbCr color conversion is performed on the restored images, shown in Figures 2(b)-(e). To alleviate the problem, we propose a new two-stage filtering approach, *the hybrid index mapping, downsampling filter* (HIMDF), to achieve optimal filtering properties. This approach has two primary advantages: 1) it provides efficient filtering in the YCbCr color space, which is critical to providing accurate luminance to 4:2:0 YCbCr streams prior to image and video compressions, and 2) it is based on the ACWMF and the SF which selectively filter the input YCbCr signals, removing impulse noise while avoiding undesired processing of noise-free samples that often results in blurring. The HIMDF provides an excellent balance between color information preservation and noise suppression, as shown in Figures 2(f) and 3(a)-(b), while providing high quality and reliable 4:2:0 YCbCr channels. Our algorithm consists of the following two-stages.

Stage 1: Processing luminance components while inheriting the chrominance components for the selected median luminance using an index mapping, center-weighted median filter (IMCWMF).

For each luminance component YCbCr of the image perform the following steps:

1. Apply the IMCWMF with the thresholds T_k, $0 \leq k \leq 3$, for detecting and removing impulse noise while inheriting the chrominance components for the median luminance, defined as a vector $\bar{\mathbf{y}}_{IMCWMF}$ of *YCbCr* samples:

$$\bar{\mathbf{y}}_{IMCWMF} = \begin{cases} YCbCr_{MED}, & \text{if } \exists k,\ d_k > T_k \\ YCbCr_{(N+1)/2}, & \text{otherwise} \end{cases} \qquad (8)$$

where $Y_{(N+1)/2}$ is the central (reference) luminance sample, $Y_{MED} = f_1(Y_1, Y_2, ..., Y_N)$, the smoothing function, defined as the median of the input set, and $CbCr_{MED}$ are the chrominance components corresponding to the median Y_{MED} obtained from $f_1(\cdot)$.

Unlike scalar y in (3), $\bar{\mathbf{y}}$ in (8) is a vector of YCbCr. In addition to noise removal from luminance components, this process attenuates noise from chrominance components because of the linear transformation from RGB to YCbCr [6] (i.e., impulse noises inherent in the R, G, and B components influence the Y, Cb, and Cr channels at the same position), see [11]. Some noise that remains at the edges of chrominance channels is eliminated through the DSF, which is presented next.

Stage 2: Processing chrominance components while performing downsampling process using a DSF.

2. Tile the chrominance data into non-overlapping windows of size N_D (downsampling window: see Figure 1), in which chrominance samples within the downsampling window are the output samples produced by the IMCWMF above. For each window, do the following:
3. Calculate $\sigma_C = \sqrt{\frac{1}{N_D}\sum_{i=1}^{N_D}(C_i - \mu_C)^2}$, where σ_C and μ_C is the standard deviation and the mean (respectively) of input chrominance data $C_1, C_2, ..., C_{N_D}$, within the window of size N_D
4. Apply the DSF, which identifies and removes noise samples while calculating the representative value from the downsampling window of size N_D. The DSF process involves the following steps. The DSF evaluates whether each of the samples C_j in the downsampling set N_D is noise-free by determining whether it is within the standard deviation from the mean of the entire window (i.e., whether $|C_j - \mu_C| \leq \sigma_C$, for each $C_j \in N_D$). The DSF then keeps only the noise-free samples and calculates the average of the noise-free samples. This average is defined as an output of YCbCr samples:

   $\bar{\mathbf{y}}_{DSF} = Y\mu(C_j)$, for only those C_j that satisfy the condition $|C_j - \mu_C| \leq \sigma_C$, $C_j \in N_D$ (9)

   where N_D is the downsampling set, $\mu(C_j)$ is the mean of only the noise-free samples in the downsampling set N_D, and Y is luminance component preserved from stage 1. Note that at least one component in the downsampling set satisfies the condition $|C_j - \mu_C| \leq \sigma_C$ (see Proof 1 at [11]).

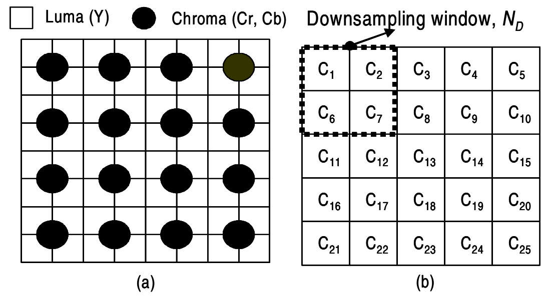


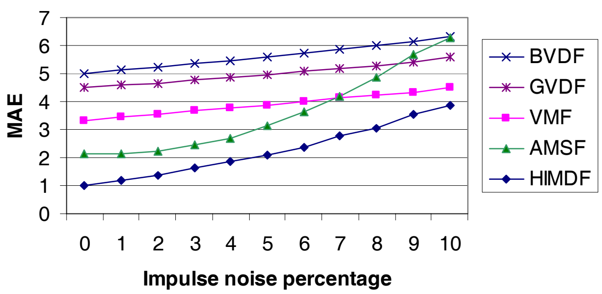
Figure 1. (a) An example of 4:2:0 downsampling and (b) an example of the DSF process. The mean $\mu(C_j)$ in (8) is computed on the downsampling set N_D, shown in dotted-line boxes.

4. EXPERIMENTAL RESULTS

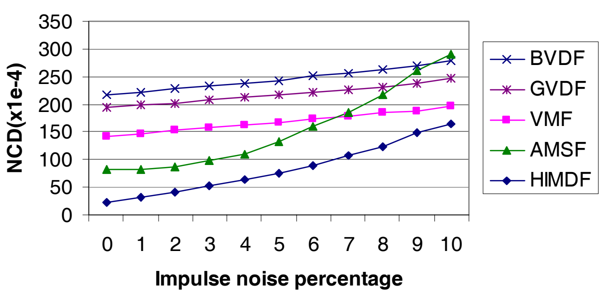
To evaluate the effectiveness of the proposed method, we compare our method (HIMDF) with the VMF, the AMSF [3], the BVDF, and the GVDF using MATLAB. In the experiment, these 3×3 filters are compared using a test suite of two well-known color video frames (*News* and *Foreman*) of three-band CIF resolution (352×288) pixels. The video frames are corrupted by impulse noise, in which the impulse probability is ranged from no corruption to 10% impulse noise with the stepsize 1% for each R, G, and B channel. The filtering results are evaluated by the commonly used metrics, mean absolute error (MAE) and normalized color distance (NCD) [10]. Their performance is combined with 4:2:0 downsampling (using an average filter) and upsampling processes, in which all the filtering approaches are starting with the same noisy image data of RGB and working in the same general framework, see [11]. The experimental results show that the HIMDF outperforms other nonlinear filters in terms of the MAE and the NCD, shown in Figures 3(a)-(b). The MAE reflects signal-detail preservation, and the NCD is a measure of color information preservation. The signal-detail preservation capability of color channels is more visible in Figure 2, which corresponds to an estimation of errors in the filters. The proposed method achieves a very small estimation error, as depicted in Figure 2(f), whereas other filters fail at image edges, as shown in Figures 2(b)-(e).

Furthermore, we evaluate the effectiveness of the proposed method for the 4:2:0 JPEG compression process with the *News* and *Foreman* frames corrupted by 4% impulse noise, in which the baseline JPEG algorithm is based on the DCT for compression. Experimental results indicate that the overall image quality using the proposed method plus the JPEG algorithm is better than that using other filters plus the JPEG algorithm, in terms of the peak signal-to-noise-ratio (PSNR) [12]. This is shown in Table 1, in which the PSNRs are the average PSNRs of all three channels (e.g., RGB).

Figure 2. Estimated luminance errors of relevant filters for 1st frame News corrupted by 4% impulse noise: (a) noisy image, (b) VMF, (c) AMSF, (d) BVDF, (e) GVDF, and (f) HIMDF (available in large images at [11]).



(a)



(b)

Figure 3. Objective measures of relevant filters for various noise percentages with 1st frame News: (a) MAE and (b) NCD.

Table 1. Performance of relevant filters plus the JPEG algorithm for 4% impulse noise. Output images coded at a compression ratio 8.8:1 are available at [11].

Image	1st frame News		9th frame Foreman	
Method	NCD	PSNR	NCD	PSNR
VMF	0.0275	28.2	0.0234	29.1
AMSF	0.0335	26.6	0.0240	29.1
BVDF	0.0368	23.8	0.0286	26.1
GVDF	0.0358	24.0	0.0265	27.1
HIMDF	0.0258	29.0	0.0226	29.7

5. CONCLUSIONS

In this paper, we have presented a new efficient prefiltering scheme (HIMDF) for the impulse noise detection and its suppression in the human perceptual YCbCr color space while performing the downsampling process. The scheme provides accurate 4:2:0 YCbCr signals not reachable by other nonlinear filters such as the VMF, the BVDF, the GVDF, and the AMSF. Experimental results have shown that the HIMDF outperforms other filters in terms of signal-detail preservation and noise suppression in color image sequences. Furthermore, the HIMDF provides accurate 4:2:0 YCbCr channels for the JPEG compression process and overall image quality. Thus, the HIMDF can serve as an efficient prefiltering tool for color image and video compression algorithms, such as the widely used 4:2:0 MPEG and JPEG.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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